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TITLE

DUAL POLARIZED THREE-SECTOR BASE STATION ANTENNA WITH VARIABLE BEAM TILT

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DUAL POLARIZED THREE-SECTOR BASE STATION ANTENNA WITH VARIABLE BEAM TILT

FIELD OF THE INVENTION

The present invention is related to the field of antennas, and more particularly to dual polarized base station antennas for wireless communication systems.

BACKGROUND OF THE INVENTION

In wireless (cellular) communications, an uplink signal at a base station antenna usually fluctuates as a result of fading caused by multiple reflections at buildings and obstacles. To reduce this fading effect, prior art base stations may have an additional antenna for the same sector to provide space diversity. This type of antenna system, however, is bulky and is generally considered to be aesthetically unpleasing. Another known way to reduce fading is through polarization diversity, i.e. reception of signals on two orthogonal polarizations (usually slant polarizations of +/- 45°). Polarization diversity allows a decrease in the number of antennas by two times in comparison with space diversity. However, the base station still needs at least three antennas for a

three-sector operation. In an urban environment, polarization diversity provides signal quality similar to space diversity. At the same time, in urban areas, the visual impact of a base station antenna has become a big concern, especially in historical or fine art architecture districts.

As is well known in the art, three polarization diversity antenna arrays can be combined in one cylindrical radome to decrease their visual impact and reduce the number of antennas for a base station to just one. Each vertical array for a 120° sector is constructed using slant 45° crossed dipoles located above a ground plane. If the diameter of this three-sector antenna is small enough, it can be used as part of a light pole, flagpole, or even as an element of church cross, so that the antenna can be invisible in the environment. Hence, it is very important to decrease the diameter of the antenna. At the same time, it is very important for an antenna to have good mechanical strength such that it can be used as an element of some structures.

Notably, prior-art three-sector antennas do not find wide field of application. One reason is their large diameters, as was discussed above. Another main reason is the need for the sector optimization.

One main method to optimize the coverage area of an antenna beam is tilting the beam downward (mechanically or electrically) from the horizontal axis in the vertical plane. More down tilt achieves a smaller cell size. In the case of a three-sector antenna, each of the 3 antenna arrays often need to have different beam tilts to suppress the interference with adjoining cells, and to provide the cell size optimization because conditions are usually quite different in different directions. Conventionally, mechanical down tilt does not work well for a three-sector antenna. To make a three-sector antenna more universal, it needs to have electrical variable down tilt for each of three sectors.

To provide a variable down tilt, an antenna may have adjustable phase shifters incorporated with its feed lines. A one-sector antenna variable phase shifter may consist of a dielectric block on a meander line moving orthogonal to its axis. This type of phase shifter has significant lateral dimensions, and cannot be used in a three-sector array without increasing of it's diameter.

Another big issue for every base station antenna is intermodulation (IM). The main method to minimize IM is to avoid metal-to-metal contacts.

Another problem with prior dual polarized dipole

arrays with variable tilt is beam squint in the horizontal plane (up to 12° with 10° tilt).

As well known in the art, the mutual coupling between crossed dipoles influences correlation of the two orthogonal polarized signals, and can disturb the effect of polarization diversity. When three antennas are combined together, the effect of mutual coupling becomes even worse. To provide polarization diversity, dual polarized base station antennas have to meet a certain port-to-port isolation specification (typically more than 30 dB), and a certain level of cross-polarization (the co-pol to cross-pol ratio must be more than 10 dB in all 120° sectors).

Another challenge with three-sector antennas is back radiation. Back radiation is characterized by front-to-back (F/B) ratio, which usually needs to be more than 25dB. Wider antenna ground plane gives better F/B. With narrower ground plane F/B can degrade.

It is one principal object of the present invention to provide a dual polarized antenna array with a compact package.

It is a further object of the invention to provide a dual polarized antenna array with a variable beam tilt.

It is another object of the invention to provide an antenna capable to meet at least 30dB port-to-port isolation.

It is another object of the invention to provide an antenna array capable to meet at least a 10dB co-pol to cross-pol ratio in a 120 degree horizontal sector.

It is another object of the invention to provide an antenna array having a 65 - 85° horizontal beamwidth.

It is another object of the invention to provide an antenna array with a front-to-back ratio of more than 25dB.

It is a further object of the invention to provide a dual polarized antenna with a high gain.

It is further object of the invention to provide a dual polarized three-sector antenna having a variable beam tilt with small (less the wavelength) diameter of radome.

It is another object of the invention to provide an antenna array with minimized intermodulation.

It is further object of the invention to provide a inexpensive antenna.

SUMMARY OF THE INVENTION

The present invention advantageously provides a compact dual polarized three-sector base station antenna with variable beam tilt in each sector, allowing wireless operators much more flexibility and opportunity to use such an antenna where conventional antennas cannot be used.

The present invention advantageously provides a variable phase shifter with very small lateral dimensions, which significantly reduces the diameter of a three-sector antenna. The feed network is located on both sides of the antenna ground plane, and the combination of the cable, microstrip and airstrip lines further reduces the lateral size of the antenna. This design also helps to eliminate parasitic coupling between feed lines, which is especially important for dual polarized antennas with higher gain and a significant number of elements.

The present invention advantageously provides a low IM level because two balun hooks and a divider for the dipoles' pair are made from one piece of metal. In addition, the transition between the airstrip and microstrip lines has the common ground plane. Moreover, special spacers are used between the three arrays to minimize contact area between them.

The present invention advantageously allows to minimize beam squint of dipole array by location of the balun hooks symmetrically with respect to vertical axis of the array.

The present invention reduces mutual coupling and improves port-to-port isolation and cross-polarization by using metal rings and strips on a cylindrical antenna radome.

The present invention achieves F/B > 25dB, and further improves a cross-polarization level with narrow (less than λ) ground plane having dual bending edges. These bent edges means also increase the structural strength of antenna.

The present invention further provides a means to create a dual polarized three-sector base station antenna with variable beams' tilt with minimization of its diameter and optimization of cross-polarization, port-to-port isolation, beam squint, IM, front-to-back ratio and mechanical strength.

The improved antenna array for transmitting and receiving electromagnetic waves has +45°and -45° linear polarizations comprising a ground plane, a plurality of dipole radiating elements along a vertical axis of the ground plane on it's outward side, and a printed circuit board attached to the backside of the board.

The ground plane is double bended on both sides and symmetrical to the vertical axis. The bended edges look outwardly from the ground plane. The first bend angle is 30°, and the second bend angle is 140 - 170° with respect to the ground plane.

Each of radiating elements includes two orthogonal dipoles aligned at an angle of +45° and -45° with respect to vertical axis, and two airstrip balun hooks, bonded to each dipole symmetrically with respect to vertical axis. By means of a 1:2 airstrip divider, two radiating elements are combined in pairs. The two balun hooks and the divider are made from one piece of metal, forming an airstrip attached to a tray and the dipoles by dielectric rivets and spacers. The airstrip has a 90° bend at the midsection in the form of a beak. Each beak extends through holes in the ground plane and printed circuit board to microstrip lines on the printed circuit board. The microstrip lines form two feed networks connected to +45° and -45° antenna ports through RF cables. The two feed network have meander line sections with an axis parallel to the vertical axis of ground plane. The antenna array can also include dielectric blocks moving along each feed network parallel to vertical axis to provide variable phase between pairs of elements. Dielectric blocks are attached to two rods, connected to the

handle. Teflon tape is disposed between the microstrip line and the dielectric blocks to reduce friction. Three of the arrays are attached to each other to form the three-sector antenna. Dielectric or metal spacers are used between the adjacent ground planes of the three arrays to minimize contact surface between them and to improve intermodulation.

The three-sector antenna can also include a cylindrical radome. On the outward surface of the radome metal pattern are rings, strips or crosses can be placed to re-radiate electromagnetic fields and to improve the antenna pattern and port-to-port isolation.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure **1** is a schematic representation of a three-sector antenna mount configured as part of a flagpole;

Figure **2** is a perspective cut-away view of the three-sector antenna with a side portion of the cylindrical radome cut away;

Figure **3** is a perspective view of the bottom area of the antenna of Fig. **2** in increased scale;

Figure **4, 5** show an outward and side view of antenna array, respectively;

Figure **6** is an inward view of the antenna array;

Figure **6a** is an increased portion of Fig. **6**;

Figure **7** is cross-section of the antenna array;

Figure **8** is a perspective view of the left and right airstrips with hooks and beak;

Figure **9** is a perspective view of two dipoles with airstrips, mounted on a ground plane;

Figure **10** is a top view of the antenna of Fig. **2**(without radome) with three antenna arrays attached together;

Figure **11** is perspective view of the antenna radome;

Figure **12** is graph of the port-to-port isolation of the antenna of Fig. **2**;

Figure **13** is a radiation pattern of the antenna of Fig. 2 measured in a horizontal plane, and

Figure **14** is an end view of antenna 1 configured as an omindirectional antenna.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

One embodiment of the present invention operates in a Personal Communication System (PCS) in a frequency band 1850 - 1990 MHz, but which invention is applicable to others frequency bands as well.

Fig. **1** shows a three-sector base station antenna **1** according to the present invention mounted on a flagpole **2** to make it virtually invisible in the environment. Fig. **1** also illustrates the need and provision of different down tilts for each of beam 3, beam 4, and beam 5, in this case, because the terrain is not flat.

Fig. **2, 3** illustrate the dual polarized (±45°) three-sector base station antenna **1** with variable sector beam tilts 1 suitable for use in the application shown in Fig. **1** or other similar applications. The antenna **1** is enclosed by a cylindrically shaped radome **6** formed of dielectric material. Metal strips **7** on the radome **6** provide antenna **1** with better port-to-port isolation than without the strips. End cup **8** seals the top of radome **6**. Inside the radome **6** are three identical antenna arrays **9** combined together in one structure, as shown in Fig. **2, 3**. Every antenna array **9** has several pairs

of crossed dipoles **10** combined in pairs **11** located on a ground plane **12**. Two RF connectors **13** (one for a -45° port and another for a +45° port) are attached to the bottom area of the ground plane **12.** By moving a handle **14,** the beam tilt of the respective array **9** is changed for both the +45° and the -45° ports. Each handle **14** has a half -U shape for convenience, and it is positioned between connectors **13** to provide easy access to it when outside cables (not shown) are connected to connectors **13**. Each handle **14** has holes **15** with numbers **16** indicating associated beam tilt (usually with 1° increments). Each pipe **17** is supported by the respective ground plane **12,** and is also used for longitudinal guidance of respective handle **14**. Respective pin **19** fixes respective handle **14** (and, respectively, the antenna beam) in a desirable position. To change the beam tilt, one needs to remove pin **19** from the holes **15** and **18,** shift handle **14** to a new position, and drive pin **19** in the holes **15, 18**. The present invention is a convenient and low cost method providing adjustable beam tilt.

Each beam 3, 4, and 5 can be individually and separately pre-set before installation of antenna **1,** or adjusted in the field. In the field, the cylindrical cover (not shown) closes parts **13** to **19,** and the antenna **1** appears as pure cylinder (see Fig.

1). A mounting base for the antenna **1** is not shown.

To understand the phase shifter/feed network of one antenna array **9**, reference is made to Fig. **4 - 6a** where the different views of antenna array **9** are shown. To provide a compact and low cost design, a feed network is provided on both sides of the ground plane **12** and combined with cable, microstrip and airstrip lines. A cable **20** is connected to each connector **13** on its one end, and to a microstrip line **21** on another end. The location of each cable **20** on the outward side of the ground plane **12** provides more space for phase shifters, located on inward side thereof. Microstrip lines **21** are printed on each printed circuit board **22** and have T-dividers **23** and meander sections **24** (see Fig. **6, 6a**). The meander microstrip sections **24** are connected through solder joints **25** to the opposing radiating dipole pair **11**. On the top of the meander section **24** there are movable dielectric blocks **26** attached to rods **27**. Two rods **27a, 27b** are mechanically connected through plate **28** to the respective handle **14**. Bridges **29** provide guidance to rods 27. Teflon tape can be used between dielectric blocks **26** and meander sections **24** to reduce friction between them. By moving handle **12,** and respectively dielectric blocks **26,** the phase velocity of the microstrip line is correspondingly changed, and the phase velocity amount is a function of how much

the meander section **24** is covered by the respective dielectric blocks **26**. Thus, the selective location of the dielectric block **26** correspondingly changes the phase difference $\Delta\varphi$ between respective radiating pairs **11**. The beam tilt θ can be found from the equation:

$$\Delta\varphi = (4\pi \mathbf{d} \sin\theta)/\lambda$$

where **d** is distance between dipoles **10**, and λ is the wavelength. By moving handle **12**, one can change the beam tilt of the corresponding antenna array **9** in synchronism for both +45° and -45 ports. Meander sections **24,** together with high dielectric constant (ε = 6 - 20) provides a reduced traveling of handle **12** for a desired phase velocity shift, and makes antenna array **9** more compact. Another advantage of this phase shifter/feed network is its small lateral dimensions, due to dielectric blocks **23** and meander sections **22** being located on the same axis.

As one can see from Figs. 4 and **7,** each radiating pair **11** consists of two dipoles **10** and two airstrips **30a** and **30b**, attached to dipole **10** and ground plane **12** by electrically non-conductive plastic rivets **31**. Each of airstrips **30a** and **30b** have a beak **32**, transformer **33,** and two balun hooks **34a and 34b** made from one piece of metal. Beak **32** and transformer **33** form a T-divider, the last divider in the feed network

distributing RF power between dipoles **10** in pair **11**.

A more detailed discussion of the transition between each microstrip line **21** and respective radiating pair **11** will now be provided. Each beak **32a** and **32b** is orthogonal to the respective airstrip **30a** and **30b**, and extends through corresponding hole **34** in the common ground plane **12** and corresponding hole **35** in the PCB **22**, and is electrically and physically coupled to the corresponding microstrip line **21a** and **21b** by a respective solder joint **25**. For solderability, airstrips **30a** and **30b** are made from brass. PCB **22** is attached to ground plane **12** by double-side sticky tape **36** having a small thickness (2 - 5 mils). Acrylic-based tape of this thickness is commercially available, and it does not significantly affect an insertion loss of microstrip line **21a** and **21b**. There is no metal on the back of PCB **22** in the configuration shown in Fig. 7. Advantageously, because microstrip line **21** and airstrip **30** have a common ground, IM is significantly reduced.

In another variant of this microstrip-to-airstrip transition, to provide more stable impedance for each microstrip line **21** and avoid additional RF losses, the PCB **22** has two metal portions on its back surface, opposing each of the corresponding microstrip lines **21a** and **21b**, as shown in Figure 6b. In this variation

case, capacitive coupling is provided through tape **36** between the grounds 50 (show) of airstrip line **33** and microstrip line **21**. In both cases, good IM performance is achieved.

Each dipole **10** is mounted on ground plane **12** by a bolt **39**. Optionally, the dipole 10 can be welded to ground plane 12. Advantageously, and in contrast with the prior art, balun hooks **34a** and **34b** are bonded to each corresponding dipole **10** symmetrically with respect to a vertical axis extending from ground plane **12**, as shown in Figs. **8, 9**. This reduces mutual coupling between adjacent balun hooks **34a** and **34b**, and also provides a reduced horizontal beam squint of antenna array **1** by 3 - 4 times over the prior art.

Further, by controlling the phase of radiating pairs, rather than of every dipole, the number of phase shifters is reduced by about half, which reduces both the cost and diameter of antenna **1**. In addition, the phase error between dipoles **10** in each pair **11** provides gain reduction δG, and also additional sidelobes with position β and level $\Re$:

$$\delta G = 20 \log [\lambda \sin (2\pi \mathbf{d} \sin\theta / \lambda) / 2\pi \mathbf{d} \sin\theta],$$

[dB]

$$\sin\beta = \lambda / 2\mathbf{d} - \sin\theta$$

$$\Re = 20 \log \{f(\beta) [\sin(2\pi \mathbf{d} \sin\theta / \lambda) / (\pi - 2\pi \mathbf{d} \sin\theta / \lambda)]\}, [dB];$$

where $f(\beta)$ is the element pattern in direction β. As seen from these equations, with small beam tilts θ, increases of sidelobe $\Re$ and gain loss δG are negligible. In the case of small tilts, even three dipoles **10** can be combined by a common airstrip for further cost reduction, and the phase can be likewise changed between these three dipoles. Advantageously, decreasing of $\Re$ is possible by destroying the periodical character of phase error in array **9**. This is done by slightly varying distance R1, R2 (see Fig. 8) from one pair **11** to another pair **11**. The difference R1 – R2 should be between 0 and $\mathbf{d}\sin\theta_m$, where θ_m is maximum tilt angle.

As shown in Fig. **7**, ground plane **12** has double bends on both its sides, shown at area **37** and **38**. The second bend **38** allows to achieve F/B > 25dB, and further improves a cross-polarization level even with a narrow (0.5 - 0.8λ) ground plane. With regards to the F/B improvement, this double bend works as kind of an RF choke. Double bends **37, 38** also increase the structural strength of antenna. By varying the width of second bend **38**, the horizontal beam of the antenna array **9** can be changed from 65° (small or zero bend **38**)

to 90° (big bend) that can be used for the cell optimization.

Advantageously, antenna array **9** can be included into a single wrap-around radome, and can be used as an independent dual polarized antenna with a very compact package.

Fig. **10** shows three antenna arrays **9** assembled together. Spacers **40** between antenna arrays **9** are used to decrease contact surface between them for better IM performance. Spacers **40** can be made from metal (with small contact area), or a dielectric material. In another embodiment, spacers **40** are formed by filling the slot between antenna arrays **9** with a dielectric (such as, FR-4 with $\varepsilon = 4$), and short the ground planes **12** at their ends. If the length of first bend **37** is $\lambda / 4\sqrt{\varepsilon}$, the result is a quarter-wave choke that improves the isolation between antenna arrays **9**, and further increases F/B.

Fig. **11** is perspective view of antenna radome **6**. Radome **6** has a number spaced coaxial metal rings **7** providing isolation improvement. Radome **6** can also can have horizontal or vertical strips **41, 42,** or a broken ring **43**, used to fine tune isolation or cross-polarization adjustment. Elements **7, 41 - 43** can be made of metal tape or conductive paint, and can be

covered by protective paint, decreasing at the same time their visual impact. In another application, rings **7** may be made from solid metal to increase rigidity of radome **6**. In this case, radome **6** is very thin and benefits from electrical performance (less RF loss in the radome), and reduced antenna weight. In another application, radome **6** may also have wide strips parallel to its axis. These strips may be used (instead of or in addition to second bend **39)** to change the beam width of antenna **1** or for it's cross-polarization optimization. Advantageously, elements 7, 41-43 do not touch any metal parts of antenna 1, which reduces risk of IM.

In Fig. **12,** measured isolation plots of antenna **1** are presented: without rings **7** (plot **44**) and with rings (plot **45**). As seen in Fig. **12**, rings **7** increase isolation by 7 - 10 dB, and antenna **1** meets a specification demand of 30 dB.

Fig. **13** shows horizontal pattern of sector of antenna **1** such at that for beam 3, 4 and 5: plot **46** is a co-pol pattern, plot **47** is a cross-pol pattern without a second bend **38**, and plot **48** is a cross-pol pattern with a second bend **38.** As can be seen from Fig. **13**, by using second bend **38** the level of cross-polarization is reduced by 5 - 10 dB.

Another embodiment of three sector antenna

according to the present invention is a dual pole Omnidirectional antenna with optimal sector coverage as shown at 90 in Figure 14. The Omnidirectional radiation pattern has less ripples in comparison to conventional omnidirectional antennas having larger spacing between the centers of radiators, because the centers of radiators in the present invention are close to each other in the horizontal plane (about .5λ).

Though the invention has been described with respect to a specific preferred embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present application. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.